A Community Energy Management Program Report

Energy
Ontario

OPERATION AND PERFORMANCE OF FOUR SOLAR DOMESTIC HOT WATER SYSTEMS

A project undertaken jointly by the
Ontario Ministries of Municipal Affairs & Housing and Energy
under the Community Energy Management Programme
(CEMP)

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ABSTRACT

In 1978 the Ontario Ministry of Municipal Affairs & Housing, with funds provided by the Ministry of Energy installed four package solar domestic hot water preheat systems in four Ontario Housing Corporation houses as part of the Housing and Energy Management Programme (HEMP).

The units chosen included two Grumman Energy Systems Incorporated systems and two American Heliothermal Corporation Systems designed for domestic hot water heating.

Monitoring equipment was supplied and installed by the Ontario Research Foundation.

This report details the monitoring programme undertaken to evaluate these units, the problems encountered during the evaluation period and the performance of the systems. The report details activities from September 1979 to March 1982.

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1.0 INTRODUCTION

The Ontario Ministry of Energy is responsible for coordinating a programme to promote the effective use of renewable energy resources. In order to introduce and promote a new technology, such as solar energy, into an established energy infrastructure, an orderly plan from research and development to demonstration and assessment leading to commercialization and market acceptance is required.

Cycle one of the planned programme involves state of the art demonstrations. As part of cycle one, the Ministry of Municipal Affairs & Housing, in co-operation with the Ontario Housing Corporation installed four package solar domestic hot water (DHW) preheat systems.

This report details the eighteen month monitoring and performance evaluation programme that was undertaken, outlines problems encountered during that period, and the performance of the systems.

The major findings of the report are:

- The package DHW system performed reasonably well over the period, however, performance was significantly below the manufacturer's claim.

- Although the systems were quite reliable. the failures that did occur could have gone undetected had it not been for the ongoing monitoring programme.

2.0 SYSTEMS DESCRIPTIONS

The systems involved in this evaluation programme are described in detail in an earlier report entitled "ASSESSMENT OF SOLAR DOMESTIC HOT WATER SYSTEMS", published by the Ministry of Energy and available at the Ontario Government Bookstore. The report deals with the design and installation problems encountered with these systems.

Of the four systems in this evaluation programme, two systems were manufactured by Grumman Energy Systems Incorporated and two systems by American Heliothermal Corporation. The basic configuration of the systems are the same. The systems are sealed and pressurized using a 50% glycol, 50% water heat transfer fluid. Each system has three flat plate absorber panels, and separate preheat tank with a wrap-around heat exchanger. One system of each type has an electric auxiliary water heater, the other two use gas auxiliary heaters. Detailed specifications for the systems are included at the end of this section.

Part way through the monitoring programme, insulation jackets were added to the backup water heaters to improve their thermal performance.

Monitoring equipment installed at all four locations is virtually identical. Solar input from the collector array to the preheat tank is recorded as well as the backup energy supplied by either electricity or gas. Separate readings on DHW usage and collector fluid flow are also available. Duplicate instrumentation for recording auxiliary energy input has been installed for reasons discussed in Section 4.1.

The locations of the four systems evaluated under this programme are all in Metropolitan Toronto. The specific addresses of the homes and the manufacturer of the system installed at each location are:

311 Atlas Avenue, Borough of York, Ontario.
- Grumman Energy Systems Inc.

14 Joplin Street North, Etobicoke, Ontario.
- Grumman Energy Systems Inc.

21 Sundance Crescent, Scarborough, Ontario.
- American Heliothermal Corp.

52 Boem Avenue, Scarborough, Ontario.
- American Heliothermal Corp.

GRUMMAN ENERGY SYSTEMS INC. SYSTEM

The system is a closed loop forced circulation system. The heat transfer fluid circulating pump circulates an ethylene glycol/water mixture through the collector array and the heat exchanger. The solar heat is transferred to the solar storage tank. The preheated water passes through the existing water heater where an energy boost may be supplied.

System Components

Collectors:

Manufacturer:	Grumman Energy Systems Inc. Ronkonkoma, New York
Quantity:	3 - each 2.8m x 1.03m (110.5 in. x 40.75 in.) overall
Total Installed Area:	8.63m^2 (93.81 sq.ft.) gross 6.78m^2 (73.74 sq.ft.) net
Specifications:	Model 60F, acrylic glazing, absorber is aluminum plate and copper tube fluid passages, coating is black paint, insulation is 2" fiberglass, enclosure is aluminum pan painted white.

Solar Storage Tank:

Manufacturer:	Grumman Energy Systems Inc.
Specification:	302 litre (80 US gallon) glass lined tank, with integral heat exchanger and 3" fiberglass insulation.
Heat Exchanger:	Aluminum wrap-around type, thermally bonded to solar storage tank, 1.08m^2 (12 sq.ft.)
Heat Transfer Fluid Circulating Pump:	Taco cartridge circulator 1/25 HP, 115V/1PH/60CYC (Part of storage tank package)
Heat Transfer Fluid:	50% inhibited ethylene glycol, 50% distilled water. Volume: 27.27 litre (6 Imperial Gallons)

AMERICAN HELIOTHERMAL CORPORATION SYSTEM

The system is a closed loop forced circulated system. The heat transfer fluid circulating pump circulates an ethylene glycol/water mixture through the collector array and the heat exchanger. The solar heat is transferred to the solar storage tank. The preheated water passes through the existing water heater where an energy boost may be supplied.

System Components

Collectors:

Manufacturer:	Americal Heliothermal Corporation Denver, Colorado
Quantity:	3 - each 2.02m x 1.07m (79.5 in. x 42.1 in.) overall
Total Installed Area:	6.48m^2 (69.81 sq. ft.) gross, 5.67m^2 (60.9 sq. ft.) net
Specifications:	Model Miromit 210, tempered ASG, water white crystal glass, single glazing, absorber is cold-rolled mild steel with schedule 40 welded steel pipe grid. Coating is electroplated selective coating, with special silicone treatment.

Solar Storage Tank:

Manufacturer:	American Heliothermal Corporation 250 litre (66 US Gallon) glass lined tank, with integral annular heat exchanger jacket, 3" fiberglass insulation. Integral 4500W/115V Electric Heating Element (Not Connected)
Heat Transfer Fluid Circulating Pump:	Grundfos, 1/20 HP, 115V/60CYC (Part of Storage Tank Package)
Heat Transfer Fluid:	50% Glycol, 50% Water, Volume: 41.0 litre (9 Imperial Gallon)

3.0 DATA COLLECTION AND SYSTEM INSPECTION

Data was collected on a sporadic basis from the time the systems were installed, until mid-September 1979. From September until December, data was collected on a weekly basis, and then bi-weekly until March 1981. Data collection was then continued on a four week cycle until March 1982. Because the systems were all installed in single family homes, access had to be arranged with each tenant. In certain cases, access could not be obtained and hence, some data is missing.

The Joplin Street house was unoccupied for an extended period of time from August 1979 to January 1981, during which time, the power to the house was turned off. The Sundance Crescent house was frequently empty during the period from March to June 1980.

On each visit, the system was visually inspected in an effort to detect any malfunction either in the solar heating system itself, the associated monitoring equipment, or the backup heating appliance. Close liaison between the consultant and the Ministry of Municipal Affairs & Housing officials was maintained in order that problems detected could be rectified as quickly as possible.

4.0 PROBLEMS ENCOUNTERED AND REMEDIAL ACTION

The systems have performed reasonably reliably over the course of the test programme with most failures associated with the experimental monitoring equipment. Of the four DHW installations, three malfunctioned at least once during the programme.

Both systems which used Rho Sigma differential controllers suffered control system failures. It was discovered early in the monitoring programme that the collector circulating pump at the Joplin Street installation was operating continuously. The system installer subsequently replaced the controller twice before making the system operative again. The precise reason for the failure was not determined. The repairs were not completed until December 1979.

The Atlas Avenue system suffered a control system failure which caused the system to not turn on at all. The controller was replaced, but as with the Joplin system, this did not solve the problem. Further visits to the site by the system installer rectified the problem, however, again the exact cause of the failure was not determined. The system was inoperative from July to September 1980.

In both cases, control system problems have not recurred.

A problem occurred with the Sundance system in clearing air locks in the collector loop after servicing of instrumentation equipment. Several service visits to purge the system of air were required before the system could be made to run reliably.

The physical condition of the systems has not deteriorated seriously. A problem was encountered with the pipe insulation used on the Boem and Sundance systems, however the problem has not recurred after repair. The original application of the exterior protective covering on the insulation was very poor and had very quickly started to come off. Without the protective cover, the insulation is subject to rapid deterioration.

In comparison with modern DHW package installations, the four installations discussed in this report would compare favourably except in the area of pipe insulation, both interior and exterior. Poor interior pipe insulation will account for a portion of the lower than expected efficiencies of the system.

The instrumentation system created the majority of the problems encountered in analysing the performance of these systems. Although the original instrumentation systems were designed to provide data accurate to $\pm$10%, they failed to meet this criteria. Problems encountered included:

- One of the integrator units failed.

- One of the collector loop flow meters failed.

- Several of the temperature sensor probes were broken because of their delicate construction.

- The sensor for measuring both flow and temperature were not of sufficient accuracy over their intended operating range.

- Temperature sensors were not properly installed. In most cases, they were completely out of the flow stream. Isolation valves were not installed to allow for maintenance and calibration of the probes.

- Electronic circuitry used to integrate temperature and flow readings had, in certain cases, drift errors of greater magnitude than the signals being measured.

- Auxiliary energy measurement was based on the "on" time of the unit. At one location, the instrument had no way of sensing whether the element in use at the time was drawing 3000 watts or 1000 watts.

Appropriate remedial action was taken to repair all of the malfunctioning or broken equipment.

Failure of the temperature probes was not surprising, considering their delicate construction and the environment in which they were placed. All the temperature probes of the design which failed have been replaced by a much sturdier model which had originally been installed at only one location. The original probes were one sixteenth of an inch in diameter which cantilevered out beyond the pipe making them very easy to damage. The replacement probes are one eighth inch in diameter and are flush mounted. The replacement probes also have armoured leads.

The cause of the one flow meter failure was not determined, however, none of the other flow meters in the same type of service have failed. The flow meter was removed, serviced by the manufacturer and reinstalled. On inspection, the disk in the meter was found to have swelled and seized, however, the reason for the swelling is unknown.

In addition to repairs, the following modifications or special measures were taken in order to increase the accuracy of the data being collected:

- The temperature sensors were reinstalled and insulated in order to ensure that the sensitive tip is properly located in the flow stream.

- Flow rates were adjusted to obtain the best accuracy possible from both the flow reading and temperature reading instruments.

- Larger pumps were installed at two locations to increase flow rates through the collectors to be within the range specified by the manufacturer of the systems.

- Electric kilowatt-hour meters or gas flow meters were installed to measure auxiliary energy usage at all locations.

- Tests were made to determine the efficiency of the gas fired auxiliary heaters installed at two of the locations. This information was necessary in order that a fair comparison could be made between the systems having gas auxiliary heaters and the ones having electric auxiliary heaters.

- Recalibration of the integrators was undertaken. This exercise was undertaken on two occasions and is necessary to remove accumulated errors due to drift.

5.0 DATA ANALYSIS

The data gathered from the four DHW systems is considered to be generally reliable. As reported in Section 3.0, a significant amount of data, however, is not available due to problems with the DHW systems themselves, the instrumentation systems, or with vacancies in the dwellings.

Data collected during the first six-month period contained errors due to instrument inaccuracies. This data was later interpolated using results from backup instruments and hence, is considered reliable.

Using cold water inlet temperature and hot water supply temperature measurement at each site, and data collected on hot water usage, theoretical values for the required energy were computed. With this factor and measured energy data, system standby heat losses were calculated.

It was felt that a positive correlation should exist between the amount of solar energy collected and the calculated standby losses. The reason for this being that the higher the solar input, the higher the average preheat tank temperature and hence, the higher the overall loss factor. This correlation was checked and proved to be reasonably good with the exception of the data at all installations over the latter part of the programme.

Tank heat loss for the electric water heater should average approximately 15-20 kilowatt-hours per week; heat loss for gas hot water heaters should average 20-25 kilowatt-hours per week based on the type, size and construction of the particular unit.

A summary of the data is shown in Table 5.1, including calculated energy requirements for heating the domestic hot water, calculated standby losses, and estimated standby losses.

Because the hot water usages, water supply temperatures, load profiles and the periods over which usable data was available vary from system to system, direct comparison of the systems using this data should not be attempted.

TABLE 5.1 DATA SUMMARY

	Number Of Weeks of Data	Solar Energy Input (kWhr)	Auxiliary Energy Input (KWhr)	Total Energy Input (kWhr)	Hot Water Usage (liters)	Calculated Energy Required (kWhr)	Calculated Stand-By Losses (kWhr)	Calculated Stand-by Losses/ Week (kWhr)	Estimated Stand-by Losses/ Week (kWhr)
ATLAS 12/9/79 - 2/7/80 14/1/81 - 17/3/82	101	3,727	6,438	10,165	161,386	8,445	1,720	17	23
JOPLIN 12/9/79 - 26/3/80 14/1/81 - 17/3/82	89	4,222	8,743	12,965	165,805	9,907	3,058	34	38
SUNDANCE 12/9/79 - 12/3/80 4/6/80 - 17/3/82	119	2,735	14,059	17,794	233,707	13,730	4,064	34	30
BOEM 12/9/79 - 17/3/82	129	4,873	20,408	25,281	414,672	21,480	3,801	30	30

6.0 ASSESSMENT OF OPERATION

All of the data collected and used in Table 6.1 is considered to be reasonably accurate. Because the usable data was collected for different periods of the year in each case, solar contributions cannot be directly compared. The cold water supply and the hot water delivery temperatures, along with the water consumption patterns also varied from location to location.

It must be remembered that when a solar system is added to a conventional DHW system the losses from storage will increase. For this reason Table 6.1 shows not only the percentage of the total energy input that was supplied by the solar systems but also the actual reduction in conventional energy requirements due to the solar systems.

Complete data from all locations is available from March 1981 to March 1982. This data was used to calculate the annual solar contributions of each system shown in Table 6.2.

The solar contribution claimed by the manufacturers are also shown for each system as well as the contribution that would have been seen at each location had the loads and water temperatures matched the assumptions of the manufacturers. The manufacturer's performance claims are based on average usage of hot water of 272 litres per day and an average temperature rise from the city water delivery temperature to the hot water supply temperature of 40°C.

The hot water usages and temperature rises were considerably different from the manufacturer's claims in the four test cases. The average hot water usages and temperature rise for the four locations from September 1979 to March 1981 were:

Atlas	228 litres/day	45°C
Joplin	266 litres/day	61°C
		45°C (after January 1981)
Sundance	281 litres/day	51°C
Boem	459 litres/day	45°C

For the period of March 1981 to March 1982, used in the calculation for Table 6.2, the average water usages were:

Atlas	247 litres/day
Joplin	274 litres/day
Sundance	290 litres/day
Boem	466 litres/day

TABLE 6.1 DOMESTIC HOT WATER SYSTEMS PERFORMANCE SUMMARY

	Solar Input (kWhr)	Total Input (kWhr)	% Solar [1]	Estimated Energy Without Solar (kWhr) [2]	Losses Due to Solar System (kWhr) [3]	% Reduction of Conventional Requirements [4]
ATLAS 12/9/79 - 2/7/80 14/1/81 - 17/3/82	3,727	10,165	37	9,784	381	34
JOPLIN 12/9/79 - 26/3/80 14/1/81 - 17/3/82	4,222	12,965	33	12,371	594	29
SUNDANCE 12/9/79 - 12/3/80 4/6/81 - 17/3/82	2,735	17,794	15	16,110	1,684	6
BOEM 12/9/79 - 17/3/82	4,873	25,281	19	24,060	1,221	15

1. % Solar = $\frac{\text{Solar Input}}{\text{Total Input}}$

2. Estimated Energy Without Solar = Calculated Requirements + Estimated Auxiliary Tank Losses

3. Losses Due to Solar System = Calculated Total Losses - Estimated Auxiliary Tank Losses

4. % Reduction of Conventional Energy Requirements

$$= \frac{\text{Solar Input - Losses Due to Solar}}{\text{Energy Requirement Without Solar}}$$

TABLE 6.2 CALCULATED ANNUAL SOLAR CONTRIBUTION

	Annual Solar Contribution March 1981 - March 1982 (%)	Annual Solar Contribution (Corrected for Manufacturer's Load Assumptions)[1] (%)	Manufacturer's Claimed Performance (%)
ATLAS	42	43	63
JOPLIN	39	44	63
SUNDANCE	24	44	63
BOEM	19	37	63

1. Hot Water Usage - 272 liters/day
Cold to Hot Water Temperature Rise - 40°C

A major concern exists with the long term operation of this type of system. Even with the existence of a comprehensive monitoring programme, three system failures occurred. Had the systems not been subjected to routine professional observation, it is conceivable that the failures could have gone completely undetected. Before the initiation of the formal monitoring programme, the Joplin system ran continuously day and night for several months.

Currently, no means of alerting the owner of a system to the occurrence of a failure exists. Because of the nature of the systems, with backup auxiliary heaters, the system user is supplied with hot water in spite of a complete failure of the solar part of the system.

From an economic viewpoint, these systems have not presented a cost effective solution to DHW heating. The average annual saving, based on three cents per kilo-watt hour electricity, averaged 52 dollars over the last year, ranging from 43 dollars to 64 dollars. When compared with the average installed price of these systems at $3203.50, a payback within the life of the system will never be realized. These systems, however, must be considered experimental in nature, and significant advances in the technology have been made since their design.

During the period of the monitoring programme very little maintenance was required on the solar systems. In most situations where maintenance was performed, maintenance on the monitoring equipment was also involved. For these reasons it is not possible to estimate the annual maintenance costs for the systems.

7.0 FINDINGS AND RECOMMENDATIONS

1. The package DHW systems performed reasonably well over the period, however, performance was significantly below the manufacturer's claims.

2. Although the systems were quite reliable, the failures that did occur could have gone undetected had it not been for the ongoing monitoring programme.

3. Further useful data on the short term performance of these types of systems is not likely from a continuation of the current monitoring effort. There will, however, be valuable information to be gained on the long term durability by annual assessment checks.